ENGINE COMPONENT IMPROVEMENT – JT8D AND JT9D PERFORMANCE IMPROVEMENTS

W. O. Gaffin
Pratt & Whitney Aircraft Group

SUMMARY

A new feasibility analysis screening method for predicting the airline acceptance of a proposed engine performance improvement modification has been developed for NASA by Pratt & Whitney Aircraft, Trans World Airlines, Boeing, and Douglas Aircraft with consultation by American, United, Eastern and Pan American Airlines. This method uses technical information derived from available test data and analytical models along with conceptual/preliminary designs to establish the predicted performance improvement, weight and installation characteristics, the cost for new production and retrofit, maintenance cost and qualitative characteristics of the performance improvement concepts being evaluated. These results are used to arrive at the payback period, which is the time required for an airline to recover the investment cost of concept implementation, and to predict the amount of fuel saved by a performance improvement concept. The assumptions used to calculate the payback period and fuel saved are discussed.

A summary of the results when the screening method is applied is presented for several representative JT8D and JT9D performance improvement concepts. An example of the input information used to develop the summary results is shown.

Based on the results of the screening method, NASA has selected several performance improvement concepts for development and evaluation.

INTRODUCTION

The general objective of the NASA-sponsored Engine Component Improvement - Performance Improvement (ECI-PI) effort at Pratt & Whitney Aircraft is to demonstrate the specific fuel consumption benefits of JT8D and JT9D component improvements which have a good probability of production incorporation. A goal of 5% fuel saving over the engine lifetime has been established for each engine model. As the first step in accomplishing this general objective, a feasibility analysis with the following specific objectives has been completed:

- perform conceptual design studies of candidate component improvements;
- assess the performance improvement concepts in terms of economics, airline acceptability, and probability of incorporation into existing engines (retrofit) and into future production of current engines; and
- develop plans for the introduction of promising performance improvement concepts.

The second step in accomplishing the general objective consists of rig testing, engine ground testing, and engine flight testing to develop the technology and demonstrate the performance improvement of selected concepts. This effort has begun on three concepts.

DISCUSSION

In arriving at desirable performance improvement concepts for development under the ECI-PI program, a long list of potential candidates was compiled. The more promising concepts from reference 1, the newer ideas being explored in the development groups at P&WA, and ideas suggested by NASA and the airplane and airline companies involved in the program were all included on this early "shopping list". The general areas of performance improvements represented by this list are summarized on figure 1.

The long list of concepts was reduced early in the evaluation effort to 28 candidates (11 for JT8D engines and 17 for JT9D engines), which were subjected to a detailed evaluation process. The reduction was accomplished by eliminating concepts with small fuel saving potential, high development risk, or other practical limitations. This preliminary screening effort was based mostly on qualitative judgements, supplemented by quantitative evaluations of critical parameters.

The detailed evaluation procedure, which was applied to the 28 remaining concepts, was developed under the contract specifically for the purpose of identifying the most promising fuel saving concepts for development under the ECI-PI program. In developing the procedure, Pratt & Whitney Aircraft and its subcontractors were striving to duplicate or simulate as closely as possible the decision making process that normally occurs when the engine and airplane manufacturers offer equipment modifications (improvements) to the airline operators. The procedure is summarized in flow chart form on figure 2. The "bottom-line" results of this procedure are payback period, percent change in fuel burned, cumulative fuel saved and contractor ranking. Payback period is the economic acceptability parameter. The change in fuel burned indicates the day-to-day effect on energy conservation to be expected from each engine or airplane equipped with a performance improvement concept. The cumulative fuel saving shows the effect of incorporating the concept in any situation where it is economically acceptable, and continuing to use it for the life of the engine. The contractor ranking represents the combined recommendations of Pratt & Whitney Aircraft and its subcontractors based on the other "bottom-line" results modified by any qualitative considerations, such as development risk and hardware commonality, which were judged to be significant.

The effect of each concept on the operational and economic characteristics of a typical fleet of airplanes on a typical route structure was evaluated using a computerized simulation. The spare engines and parts provisioning requirements were estimated by airline maintenance experts. The results of the economic evaluation of each application of a concept was compared to an acceptability standard (required payback period) which was established earlier on the basis of airline requirements. Only those applications which met or bettered this standard were considered for the cumulative fuel saving estimate step of the evaluation. The evaluation procedure was developed and applied by a team which includes the manufacturers of the JT8D and JT9D engines and the airplanes in which they are used, plus several major airlines which operate this equipment. Pratt & Whitney Aircraft defined the effects of each component improvement concept on the engine characteristics using standard design, evaluation, and pricing procedures, and also provided overall coordination of the evaluation process. The Boeing Commercial Airplane Company defined the effects on the 727, 737, and 747 airplanes and the Douglas Aircraft Company defined the effects on the DC9 and DC10 airplanes, using their standard design evaluation and pricing procedures. Trans World Airlines estimated the operational and economic effects in typical fleets and typical route structures using a previously developed computer simulation. American Airlines and United Airlines, serving as consultants to P&WA, BCAC, DACO and TWA, completed the evaluation team. Their function was to insure that the overall evaluations, and the TWA evaluation in particular, are typical of a major portion of the U.S. airline business. Eastern Airlines and Pan American Airlines served as consultants to NASA on this and other programs. Their efforts in the ECI-PI program served to insure that the evaluation results have even broader applicability.

The general input assumptions to the evaluation procedure are summarized on figure 3. The fuel prices and maintenance labor rates were selected by NASA based on the recommendations of the evaluation team to be consistent with the values used in related studies. Projections of the future sales of JT8D and JT9D engines were established for the evaluation by averaging the individual projections made by the Pratt & Whitney Aircraft team members. The required payback period, which will be discussed later, represents a consensus of the airline members of the team. The fleet size and route structure used with each airplane/engine model combination were defined by the airline members of the team to be typical of the use of this equipment in U.S. airline service. The annual fuel usage for each engine model represents an average of the entire U.S. airline industry, as reported to the Civil Aeronautics Board.

Perhaps the best way to explain the evaluation procedure is by an example. The evaluation of a modification to the JT8D high pressure turbine, applied at the time of engine production and as a retrofit to engines already in service, is summarized on figures 4 and 5. This modification requires additional steps and processes in the manufacture of the cooled turbine blades and the associated outer air seal ring, which will increase the price of these parts and of the complete engine. These increases combine with spare engine and spare parts requirements to increase the total investment cost associated with each airplane that an airline buys. The higher parts prices also result in an increase in the cost of materials used in maintaining the engines. However, the improved performance provided by the modification reduces the turbine temperature required to achieve a given thrust level, extending the time between engine removal for maintenance, and reducing the maintenance labor required per engine operating hour. The performance improvement is indicated by the thrust specific fuel consumption (TSFC) reductions shown on the figures. The TSFC reductions combine with any engine or installation weight changes (there were none in this case) to determine the fuel savings that will result if the concept is used in the typical fleet on the typical route structure. The fuel cost saving follows directly from the fuel saving, and combines with the maintenance cost change to produce the change in annual operating cost per airplane. Dividing the incremental investment cost per airplane by the incremental annual cost saving yields the payback period. This estimated payback period must be compared to the standard defined on figure 6 to determine the acceptability of the concept in each situation being evaluated.

The maximum acceptable payback period was calculated based on investment criteria and tax rule interpretations defined by the airline members of the team. While the airlines did not agree exactly in detail, the net result of their respective criteria and interpretations was remarkably close agreement on the desired capitol recovery rate and resulting maximum acceptable payback period. For this evaluation, the economic life of a new engine was assumed to be 15 years. It follows that the remaining economic life of a used engine being retrofit is 15 years minus the age of the engine at the time of retrofit. The maximum acceptable payback period then becomes a function of engine age as shown on figure 6, with the high value of 6 years for a new engine decreasing to zero (instantaneous payback) for a 15 year old engine. Applying this payback period standard to the estimated payback periods shown on figures 4 and 5, it may be concluded that the concept being evaluated should be acceptable to the airlines in new purchases of the 727, 737, and DC9, and for retrofit in 727 engines which are 4 years old or newer. The estimated payback period for retrofit in the DC9 and 737 (7.3 years) falls outside the acceptable limits, which means the airlines would probably choose to operate these airplane/engine combinations without incorporating the modifications. A practical consideration may arise which could reverse this latter conclusion and it is described here to illustrate the limitations of the evaluation procedure, and to underscore the need for direct airline participation in such an evaluation. An airline which operates 727 airplanes and either DC9 or 737 airplanes might choose to retrofit all of its JT8D engines to maintain commonality, with the accompanying benefits of parts and engine interchangeability, reduced spares inventory, and simplified maintenance procedures.

Figure 7 illustrates graphically the procedure used to estimate the cumulative fuel saving that will result from incorporating the concept in every situation where it is economically acceptable. The "engine entering service" curve is based on actual airplane sales through the year 1976, and represents the team consensus projection from that time onward. The "engines being retired" curve is the "engines entering service" curve displaced 15 years to represent the assumed 15 year economic life of each engine. Only the JT8D-15 and -17 models are considered here since the concept being evaluated applies only to these models, which have cooled high pressure turbine blades. The start of service date for the concept was estimated to be January 1980, based on a review of the development effort required. The "engines entering service" curve of figure 7 projects about 800 engines to enter service between 1980 and 1990 (the cut-off date chosen by NASA for the evaluation). Since the concept is economically acceptable for all of these new engines, and will reduce their fuel consumption until they are retired 15 years later, the shaded area between the curves represents the number of new engine-years that are affected. The concept is also available for retrofit starting in 1980, and will be applied to Boeing 727 engines that entered service in the 4 years before 1980. For convenience, the airlines would probably choose to install the modified parts when the engines come into the maintenance shop for other reasons. This will spread the introduction of the concept over the time it takes for all engines to return to the shop, approximately 3 years. This analysis assumes all of these engines will be retired when they are 15 years old regardless of when the concept was incorporated. The retrofit engine-years affected would be represented by the shaded area marked on figure 7 if all three airplane models were to be retrofitted. Since only the 727 airplane engines were found to be economically feasible for retrofit, the engine-years were reduced proportionally.

The engine-years affected are combined with the average annual fuel usage of the JT8D and the percent fuel saving estimated for the concept to produce the cumulative fuel savings shown on figures 4 and 5, which combine for a total of 340×10^6 liters (90×10^6 gallons) of fuel saved.

The evaluation procedure was applied to all 28 candidate concepts, and the team then ranked the concepts. As shown by the flow chart in figure 8, NASA combined the results of the evaluation with development program schedule and cost information supplied by the manufacturers and NASA's own technical and funding considerations to make the final decision to include a concept in the ECI-PI development and demonstration effort. The concepts thus selected are listed in figure 9 along with a summary of the evaluation of each selected concept. NASA has funded development of the three concepts included in the boxes in figure 9 and work has begun on the programs. The others are expected to be funded and started during the next several months.

CONCLUDING REMARKS

Under the NASA sponsored Engine Component Improvement - Performance Improvement Program, an effective evaluation process was developed and successfully demonstrated. Using this process, a team formed by Pratt & Whitney Aircraft and including representatives from airframe manufacturers and the airlines evaluated 28 performance improvement concepts and identified 9 that were judged to have a high probability of meeting the economic and performance requirements for implementation. NASA has funded development and demonstration efforts for three of the nine concepts and these programs are currently in progress.

REFERENCE

1. Gray, D. E.,: Study of Turbofan Engines Designed for Low Energy Consumption - Final Report. NASA CR-135002, April 1976.

Considered well over 100 candidate concepts derived from:

- **Improved component aerodynamics**
- **Improved flowpath sealing**
- **Blade tip clearance control**
- **Improved turbine cooling effectiveness**
- **Improved turbine materials and coatings**
- **Duct and nozzle aerodynamic refinements**
- **Nacelle aerodynamic refinements**
- **Forced exhaust mixers**
- **Advanced nacelle materials**
- **Advanced fuel control**

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Figure 1.- General areas of performance improvement considered.

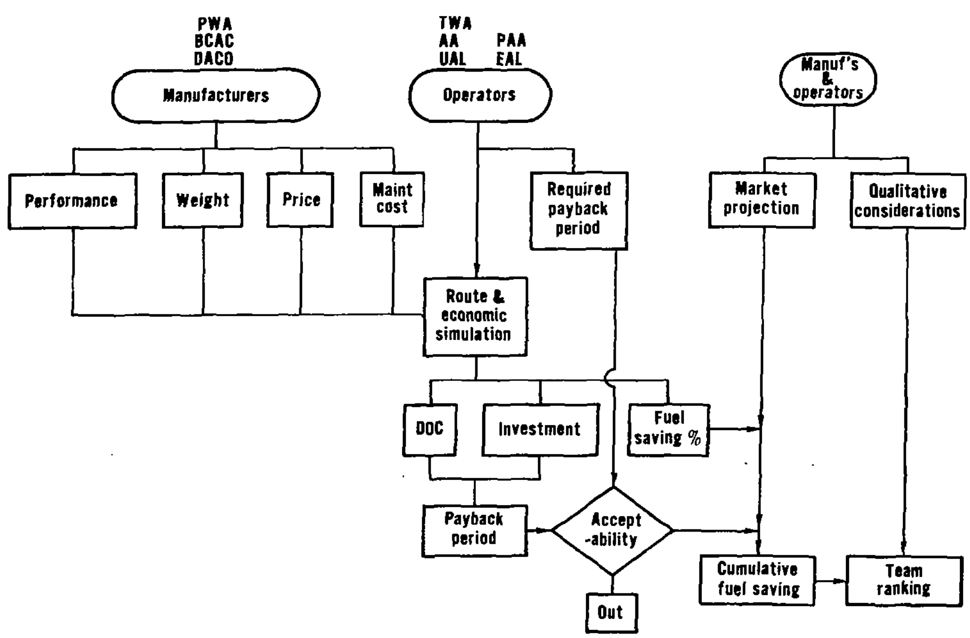

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Figure 2.- Detailed evaluation procedure flow chart.

Fuel price	9.2¢/liter (35¢/gal) domestic, 11.9¢/liter (45¢/gal) international			
Maint. labor rate	30$/hr. (fully allocated)			
Spares requirements	Variable			
Market projection	Team consensus			
Max. acceptable payback period	Function of engine age			
Airplane model	DC-9-50	727-200	DC10-40	747-200
Engine model	JT8D-17	JT8D-15	JT9D-59	JT9D-7 or -70
Fleet size	18	39	28	11
City pairs	62	129	45	24
Flights per week	714	1416	397	136
Avg. stage length, km (N.Mi)	669(361)	1093(590)	2967(1602)	5545(2994)
	JT8D		JT9D	
Avg. annual fuel usage, 10^6 liters(gal) per eng-yr	3.8(1)		11.3(3)	

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Figure 3.- Summary of evaluation input assumptions.

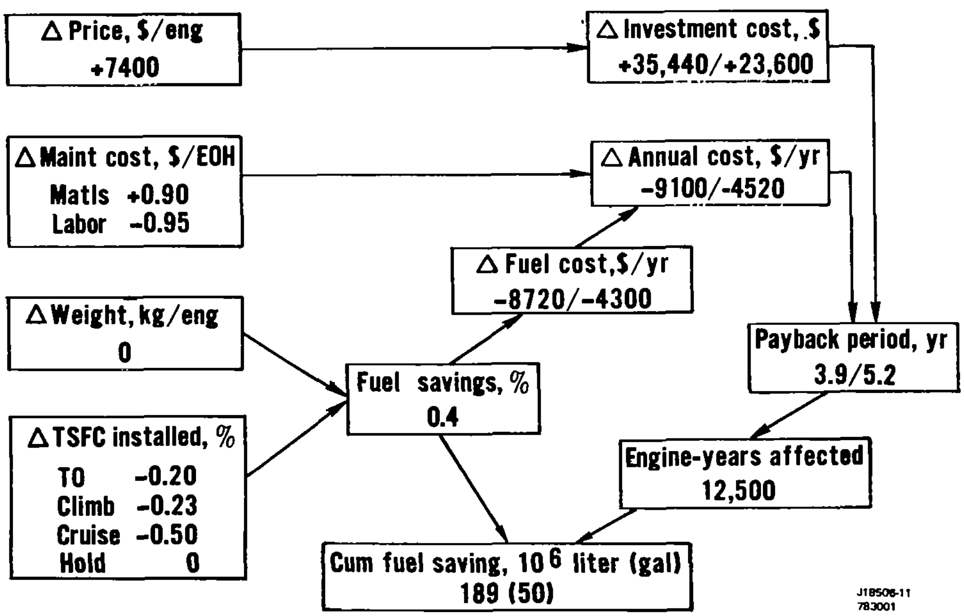

Figure 4.- Evaluation of JT8D revised HPT outer air seal for new buy 727-200/DC9-50.

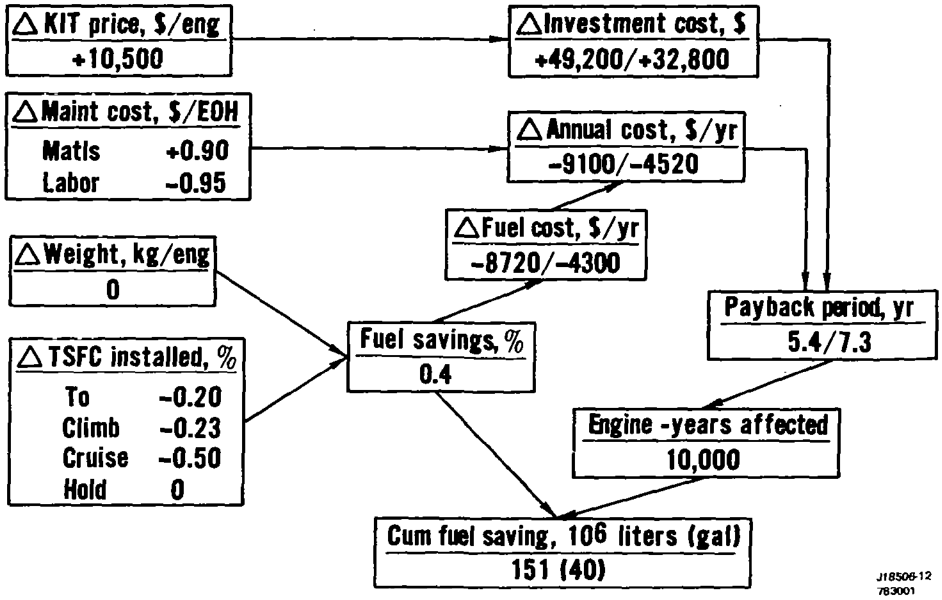

Figure 5.- Evaluation of JT8D revised HPT outer air seal for retrofit 727-200/DC9-50.

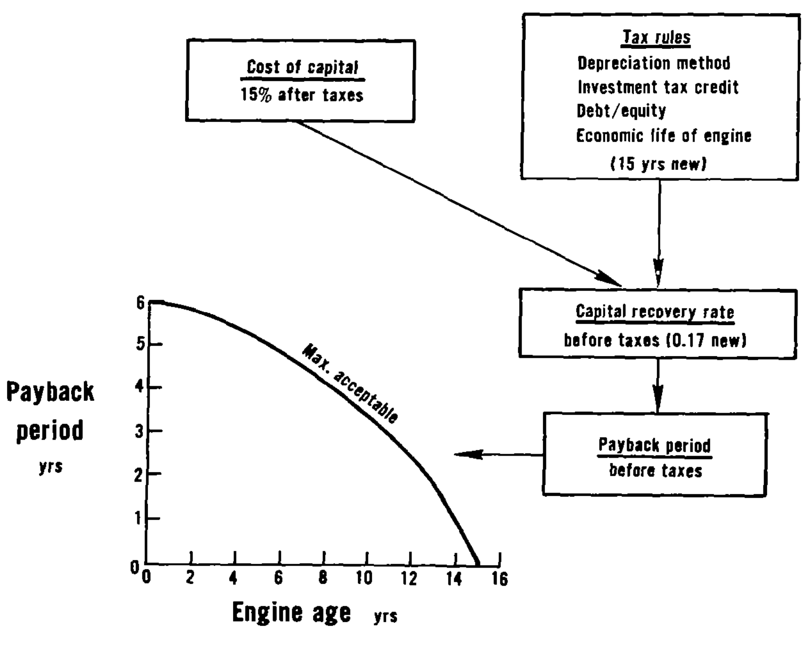

Figure 6.- Maximum acceptable payback period determination.

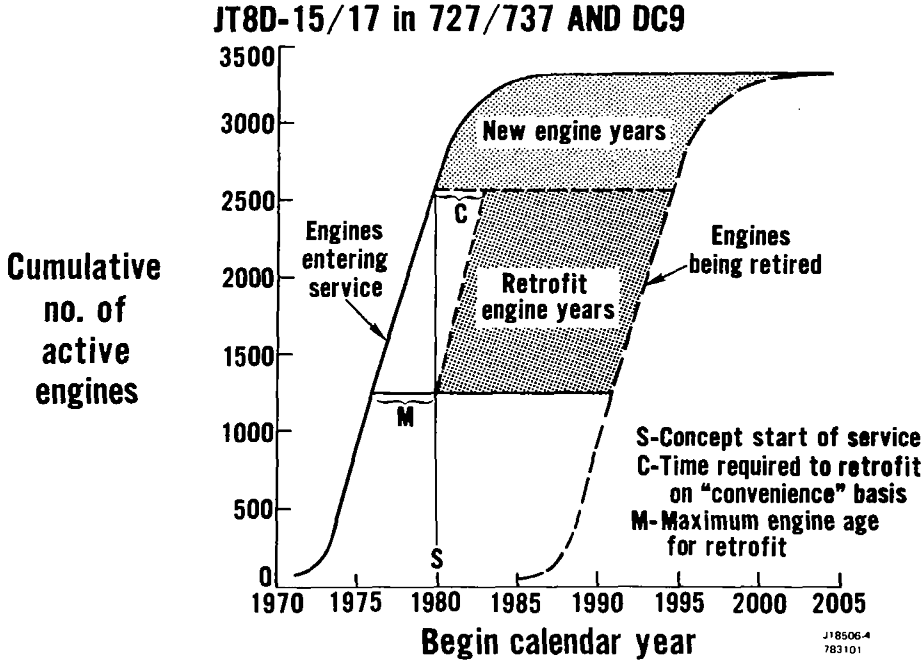

Figure 7.- Cumulative fuel savings estimate procedure.

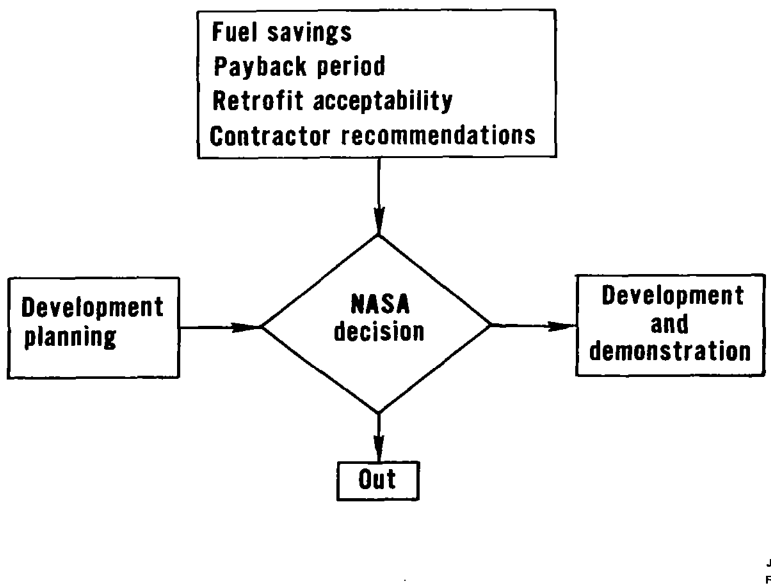

Figure 8.- NASA concept selection procedure.

	Start of service date	Payback period* New	Payback period* Retrofit	Fuel saving %	Fuel saving Cum, 10^6 liters	(gal)
Total JT8D				**2.7**	**3860**	**(1023)**
Revised HPT outer air seal (-15/17)	1/80	3.9/5.2	5.4/7	0.4	340	(90)
Root discharge of HPT blade cooling air (-15/17)	6/81	0/0	0/0	0.8	980	(259)
Abradable, trenched HPC blade tips	3/81	1.2/1.4	5.0/6	1.0	2220	(589)
DC9 reverser stang fairing	1/79	-/0.7	-/0.7	0.5	320	(85)
Total JT9D				**3.4**	**9280**	**(2456)**
Improved HPT active clearance control (-70/59)	6/79	1.0/2.1	6 /12	0.9	1770	(468)
3.8 aspect ratio fan (single shroud) (-7)	1/80	1.8/ -	10/ -	1.5	2720	(720)
Trenched HPC blade tips	3/81	0.1/0.1	0.7/0.3	0.4	1860	(493)
Ceramic HPT blade tip seals	1/82	0.3/0.5	0.5/0.7	0.4	1950	(516)
Thermal barrier coating on HPT vane platform	1/82	0/0	0/0	0.2	980	(259)

*727/DC9 or 747/DC10

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Figure 9.- Evaluation results for recommended concepts.